DESIGN AND EXECUTION OF THE UNBONDED OVERLAY BASELINE EXPERIMENT AT THE NAPTF

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ABSTRACT

The Innovative Pavement Research Foundation (IPRF) executed a contract for the development of a Roadmap document to lay out the plan for the investigation of unbonded concrete airfield overlays. The scope of work also included the design an execution of the first phase of the experiment described by the Roadmap. This paper presents the development of Roadmap document, and execution of the first phase of the research. The Roadmap document focused on the development of a research approach which could be accomplished in manageable portions of research activity. It deals with identification of the performance related parameters, and structuring of these into functional research project increments. Three phases of work were identified within the Roadmap to address all the issues relevant to unbonded overlay performance. The first phase of research was designed to address a limited number of the factors identified in the Roadmap, including existing pavement condition, the influence of matched and mismatched joints, and the relative thickness of underlying and overlay slabs. The paper discusses the first phase experiment design and construction. It was necessary to factor construction and instrumentation elements into the experiment design, as well as physical limitations of the loading facility. All phases of the research are to be conducted using the accelerated loading equipment at the National Airfield Pavement Test Facility (NAPTF). The paper also discusses the first phase loading plan developed and executed at the Facility. Loading was conducted for both tandem and tridem gears on parallel pavement tracks. Response data was collected at multiple load levels, but primary load repetitions were conducted at a single load level. Finally, the paper discusses the distresses which resulted from the loading. Distress types, identified mechanisms, and implications of certain distresses are also addressed.

INTRODUCTION

Numerous airport pavements have been constructed using portland cement concrete pavement for many decades. While these pavements perform well, eventually all pavements require rehabilitation or replacement. An unbonded concrete overlay offers an attractive alternative for several reasons. One reason is that by leaving the existing pavement in place, the in situ conditions of subgrade and base layers are essentially undisturbed, and even though the best available construction practices are used, minimizing any opportunity for additional consolidation or settlement to take place during use. Another very advantageous reason is that the existing pavement can be taken into consideration in structural design, typically resulting in a thinner and less costly required pavement layer.

Unbonded overlays have been used successfully in the past, and yet much is still unknown about the mechanisms by which they perform, and consequently room for improvement exists for design procedures. Past researchers, including Rollings [1], recognized the need for additional controlled performance data. Advanced design procedures, including those developed by the FAA, Brill [2] and Guo [3], allow greater precision in design, but require supporting calibration data. Again, this opportunity indicates that additional cost savings can be realized in the form of design improvements and enhanced performance. This project involves the design, construction, loading, and analysis of unbonded overlay pavements at the National Airfield Pavement Test Facility (NAPTF) of the Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey. This paper discusses the background of the project, and the implementation of the initial unbonded overlay Baseline Experiment.

ROADMAP

The development of the master plan, or Roadmap, for research related to unbonded concrete overlays was an important element in defining critical factors related to pavement performance and assisting in prioritizing those factors to be addressed during the Baseline Experiment. Initially, all the factors anticipated to significantly affect the performance of unbonded airfield concrete overlays, beginning with a previous IPRF report by Khazanovich [4], and which could feasibly be studied in the accelerated testing environment at the NAPTF, were identified. For the purpose of developing the Roadmap, these were catalogued as shown in Table 1.

It was proposed that the assessment of these variables would be undertaken using dimensionless analysis. This approach has several advantages, including making it possible to use value ratios to determine values missing from the matrix. This improved the expediency of the actual experiment design which can be constructed and tested, while providing a means of estimating values not directly tested. This greatly improves the efficiency of the actual experiment design and construction costs. The approach to dimensionless analysis is summarized in Table 2.

Table 1.
Experimental "Roadmap" Variables.

Structure Variables	
	Overlay Thickness
	Underlying Slab Thickness
	Overlay E-Value
	Underlying Slab E-Value
Condition Variables	
	Different levels of Structural Condition Index (SCI)
	Same SCI/different distress combinations
Discontinuity Variables	
	Cracks and joints
	Matched/mismatched
Gear Configuration Variables	
	Load
	Type (single, dual, dual-tandem, tridem)
	Wheel wander
Support Variables	
	High
	Medium
	Low
Load Transfer Variables	
	Dowels
	No dowels
Interlayer/Adhesion Variables	
	Thickness
	Degree of adhesion

The approach to dimensionless analysis is summarized in Table 2. From this experimental matrix, a master plan was developed consisting of three core recommended experiments. The first is defined as the Baseline Experiment and is described in this paper. The second is the SCI Validation Study, which is focused on determination of the effect of structural condition index on the performance of the overlay. The SCI Validation Study began in November 2006. The third recommended experiment addresses interlayer stress development. This experiment will evaluate the effect of interlayer thickness and adhesion level. No schedule currently exists for this work.

Compilation of the work outlined in the Roadmap document results in a broad range of variables that may influence the performance of unbonded concrete airfield overlays. The data collected for this variety of conditions will provide measured pavement responses to tandem and tridem axle loads representative of large aircraft. This information can subsequently be used to describe models for refined overlay design methodology, and as a framework for formulating subsequent experiments.

DESIGN OF BASELINE EXPERIMENT

The design of the Baseline Experiment drew from the information assembled during the Roadmap activity. A refined design matrix was developed, specific to the Baseline Experiment conditions. Further, it was determined that it was not reasonable to attempt to address too many parameters at once. A finite space was available for the experiment construction. When practical joint spacing was considered, it became clear that it would be necessary to limit the number of variables addressed, particularly when replication of factors was considered. Constraints are provided by the physical geometry of the test area, the loading range of the loading device, and the necessity to develop sections that could be failed by repetitive loading within a reasonable testing time.

For the Baseline Experiment, it was not possible to include some of the variables contained in the Roadmap, for example high and low strength subgrades. The predominant factors were determined to be the ratios of combined slab thickness and concrete elastic modulus factors for the underlying and overlay slabs. The same concrete mix was used for the construction of both top and bottom slabs, so the initial elastic modulus values were constant. The project team also considered it important to address the effect of joints and cracks being matched or mismatched in the overlying slab. After consideration of this condition, it was concluded that by creating a significant weakened plane, cracks and joints could both be reasonably modeled as the same condition. A D/2 saw cut was determined to be a reasonable means of introducing this discontinuity into the bottom slab. The interface condition was established as a single partially bonded level determined by the asphalt interlayer. For the Baseline Experiment, the interface condition remained constant.

Loading was planned using both dual tandem and tridem gears, therefore it was important that the pavements constructed perform in a reasonable manner, and fail in a reasonable number of passes, for both configurations. The general gear configurations used by the test vehicle are shown in Figures 1 and 2. These gear configurations approximate those of actual B767 and B777 aircraft.

Table 2.
Experimental Dimensionless Parameters and Ranking.

1. Structure and Conditon Parameters
$E_{ol}h_{ol}/E_{sl}h_{sl}$ - primary
h_{ol}/h_{sl} and E_{ol}/E_{sl} - secondary
2. Discontinuity Parameters
x_L/l
x_T/l
3. Gear Configuration Variables
$ESWR/l$
4. Load Transfer Parameters
$AGG/(k \times l)$
$D/(s \times k \times l)$
5. Support Variables
$k \times l$
6. Interlayer / Adhesion Parameters
$(heW - heU)/(heB - heU)$
heU/h_{ol}
$(heU/h_{sl}) \times (E_{ol}/E_{sl})$

where: h_{ol} and h_{sl} = overlay and underlying slab thicknesses, respectively
E_{ol} and E_{sl} = overlay and underlying slab elastic moduli, respectively
x_T and x_l = transverse joint and longitudinal joint offsets, respectively
$l = \left[\left(E_{ol} \times \left(h_{ol}^3 + (E_{sl}/E_{ol}) \times h_{sl}^3\right)\right)/\left(12 \times (1-\mu) \times k\right)\right]^{0.25}$ = radius of relative stiffness
μ = Poisson's ratio = 0.15
k = modulus of subgrade reaction
$ESWR$ = equivalent single wheel radius
AGG = stiffness of the elastic joint
D = composite (springs in a series) shear stiffness of the joint
S = dowel spacing
heW = in-situ (working) effective thickness, determined from HWD testing
heB = effective thicknesses assuming fully bonded conditions
heU = effective thicknesses assuming no bond

ANALYSIS FOR DESIGN THICKNESS

Multiple loading analyses were conducted to predict the performance of the potential pavement sections. Numerous analysis tools were used for this activity including LEDFAA, FEDFAA, the PCA method, and EverFE [7].

The performance of dowels in longitudinal and transverse joints was considered, as well as the final slab panel size selected for use in the experiment. From this analysis, final overlay slab size was determined to be 12.5 ft. in both longitudinally and transversely. Dowels were included in both longitudinal and transverse joints. Typical stress distributions from EverFE are illustrated in Figures 1 and 2. Table 3 provides typical computed stress and deflection values at various points with the load placed adjacent to the joint.

The results from combined assessment of the variables and constraints cumulated in the design configuration shown below in Figures 3 and 4.

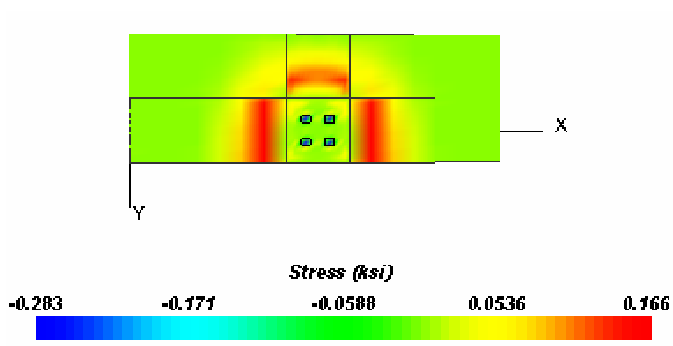

Figure 1. Example of Stress Distribution from Tandem Load.

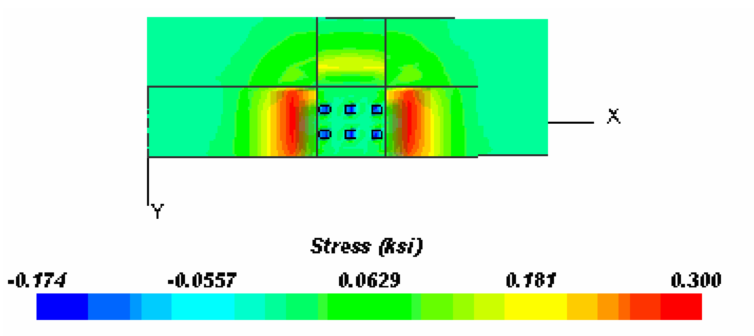

Figure 2. Example of Stress Distribution from Tridem Load.

Table 3.
Example Stress and Deflection Values for Selected Locations Along Loaded Longitudinal Joints.

	Left Slab Corner	Left Axle	Center Axle	Right Axle	Right Slab Corner
Undoweled Slab					
OL Stress (psi)	226	331	346	340	212
Slab Stress (psi)	410	834	935	840	413
Deflection (in.)	0.075	0.114	0.137	0.113	0.075
Doweled Slab					
OL Stress (psi)	243	331	348	339	234
Slab Stress (psi)	374	824	932	837	381
Deflection (in.)	0.074	0.111	0.136	0.112	0.074

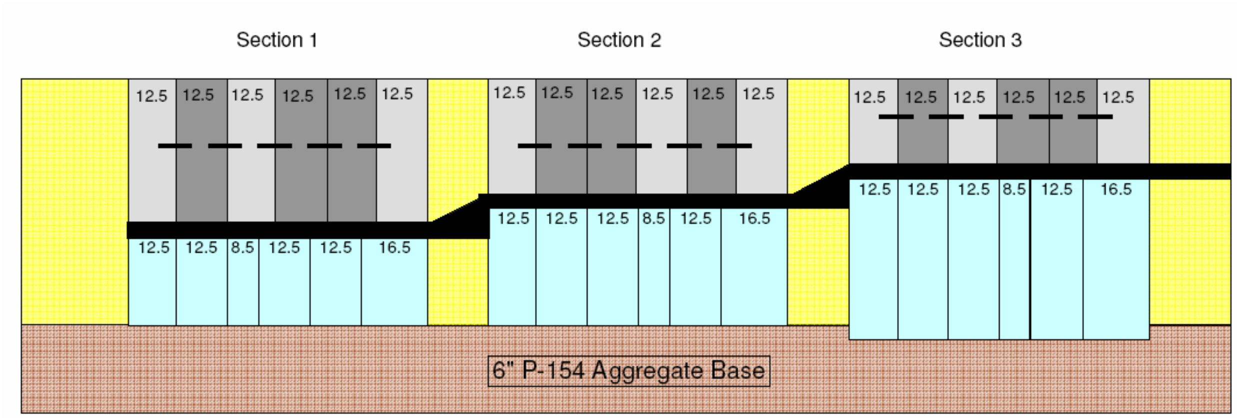

Figure 3. Experimental Design Configuration, Showing Transverse Joint Spacings.

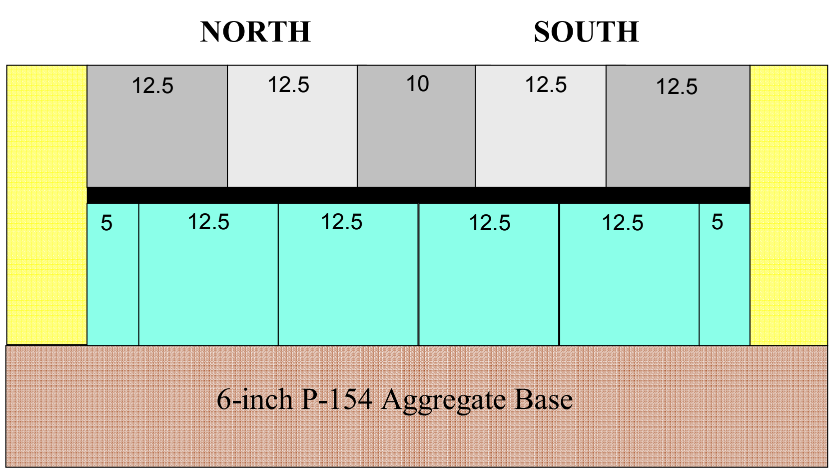

Figure 4. Longitudinal Joint Locations for Top and Bottom Slabs.

CONSTRUCTION OF THE BASELINE EXPERIMENT

Construction of the test pavement sections was carried out from January, 2006, through April, 2006. The FAA staff provided a prepared subgrade meeting CBR of 7 to 8. This was followed by placement of a six-inch layer of P-154 aggregate base material. The material was constructed only five inches thick for Section 3 to accommodate the planned 10-in. bottom slab thickness. This slab thickness was selected to optimize the h_{ol} and h_{sl} ratio, but the reciprocal section was construction at 9 in. thickness to facilitate failure of the experimental pavement.

The bottom concrete slab was constructed during February. This construction provided the thickness variation for the experimental plan. Section 1 was constructed at a target thickness of 6 in., section 2 at 7.5 in., and section 3 at 10 in. Thickness changes between sections were accomplished in the transition area between the 75-ft. test sections. This bottom slab provided the platform for completing construction of the interlayer and unbonded overlay with a level surface to permit loading. Top slab sections were reversed from those of the lower slab, with thickness of 9 in., 7.5 in., and 6 in. for sections 1, 2 and 3, respectively.

An asphalt interlayer was placed between the two concrete layers, as consistent with previous experience and practice. Wooden blockouts were used to form channels in the asphalt layer for placement of instrumentation wires for the top slab instrumentation. These were later backfilled with cold patch, once the wires were installed. These blockouts interfered with the paver screed, and resulted in variation in the asphalt layer from approximately ¾ in. to 2 in. This variation is reflected in the elevation data depicted in Figures 5 and 6. The bottom slab was coated with a cement slurry beneath the asphalt interlayer to facilitate later removal of the asphalt with the top slab, allowing inspection of distress development in the bottom slab.

The concrete mix design used has been developed over a period of years to provide the most reasonable results for accelerated testing at the NAPTF. The mix design consists of:

- 1600 pounds of # 57 coarse aggregate
- pounds of fine aggregate
- pounds of Type I cement
- 250 pounds of Class C flyash
- 250 pounds of water

While this mix is rather unconventional, it was determined after extensive testing to be the best combination of locally available materials for achieving a target flexural strength of 700 to 750 psi. Additional information has been documented by Hayhoe [5] and McQueen [6]. For this construction, however, average flexural strengths were actually 500 to 550 psi. The discrepancy may be the result of changes made in cement manufacture, but that is not confirmed.

Dowels used in the overlay were one-inch diameter, eighteen inches long, and supported by wire baskets. Dowels were placed 12-in. center-to-center in both the longitudinal and transverse joints, leaving clear space at each corner to prevent conflicts. Some weeks after construction,

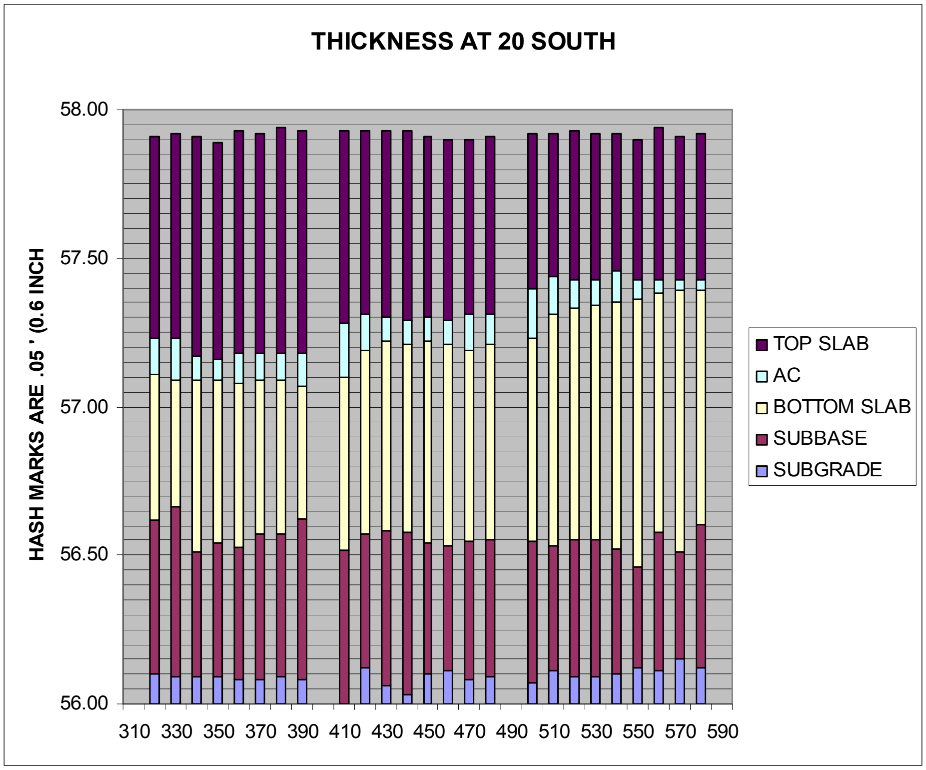

Figure 5. Thicknesses at 20 ft. South of Centerline.

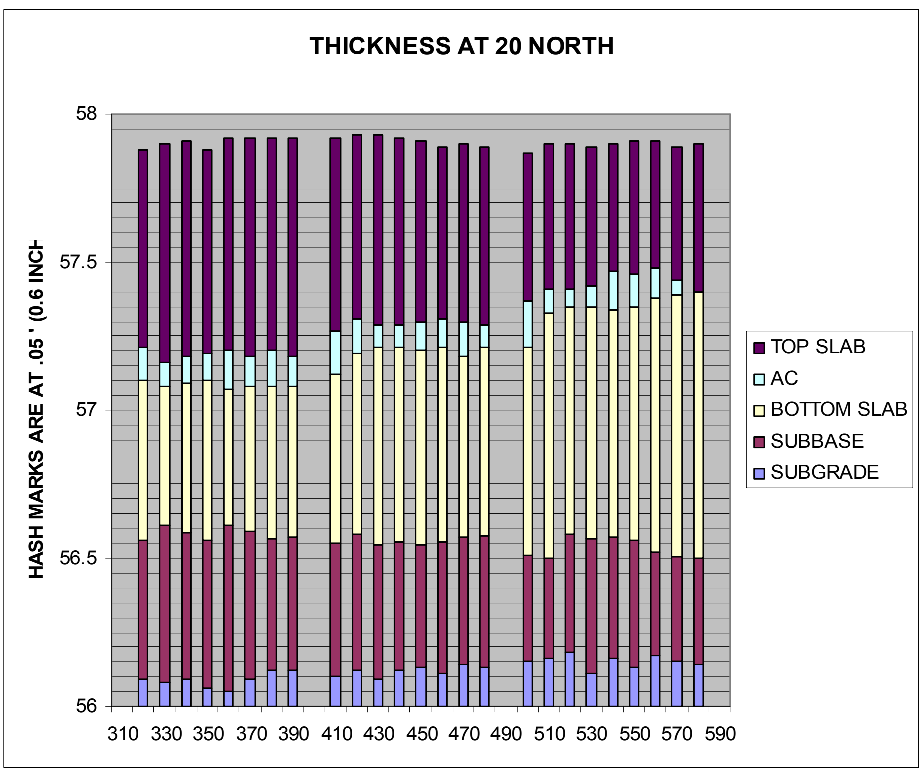

Figure 6. Thicknesses at 20 ft. North of Centerline.

hairline cracks were observed at some dowel locations in the 6-inch overlay section. These cracks remained virtually unchanged throughout the experiment, and had no observed effect.

ACCELERATED LOADING

After a period of testing at lower loads, loading of the pavement test sections proceeded at a 50,000 pound per tire load level from August to November of 2006. Figure 7 illustrates the wander pattern applied during the loading period. The North wheel track was loaded with the tridem, and the South with the tandem. Loading continued until each section developed an approximate SCI of 20. This resulted in sections receiving different numbers of load passes.

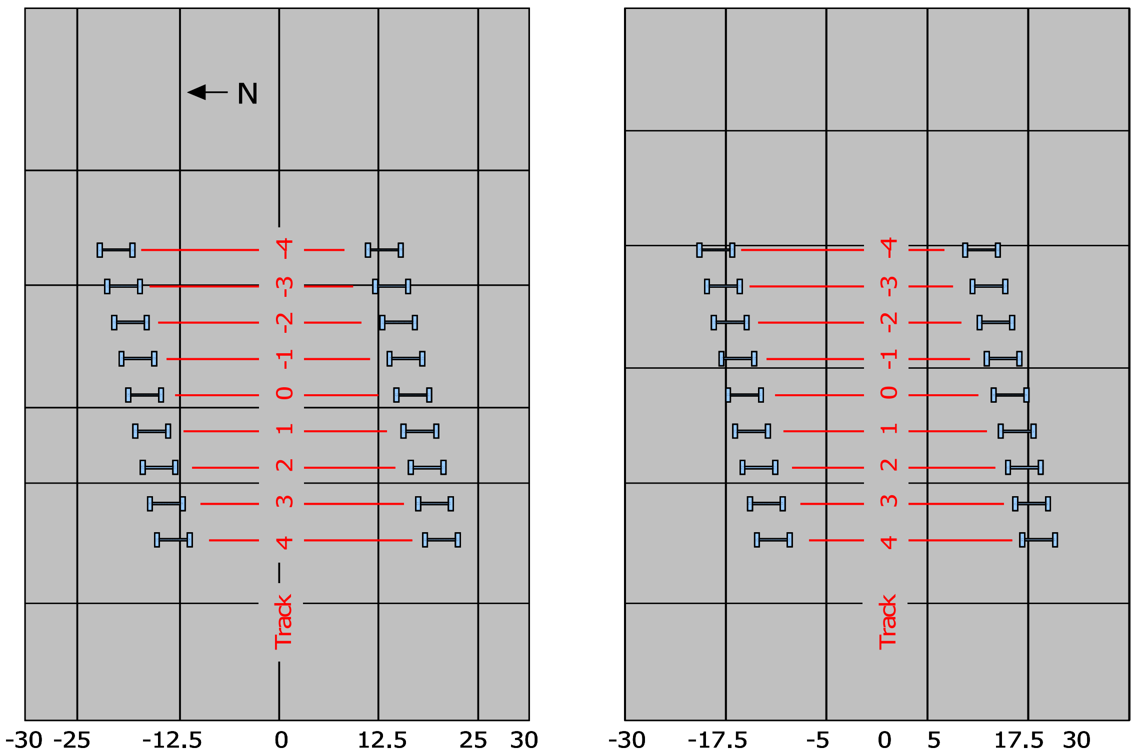

Figure 7. Loading Positions Relative to Underlay (left) and Overlay (right) Joints.

DISTRESS DEVELOPMENT

Load-related distress began to develop with cumulative load passes. Longitudinal cracking developed first in all the pavement sections. Distress developed more quickly in the sections with tridem loading than for those with tandem. The sections were loaded until an SCI level of approximately 20 was achieved in the overlay slab sections. The cumulative loading passes and resulting SCI for each section is summarized.

DISTRESS MONITORING

Distress monitoring of the overlay was accomplished using a series of conventional manual distress surveys, and digital imaging at certain points during the distress development process. Figure 8 is a composite example of several digital images, illustrating the use of this technology to capture surface distress. This image represents imaging with the equipment set up such that a 0.5 mm dimension is the size of a single pixel. Images were also recorded of the pavement set up so that a 0.3 mm dimension is one pixel size. Cumulative plots of the manual distress surveys, as provided by SRA personnel, are provided in Figures 9 through 11.

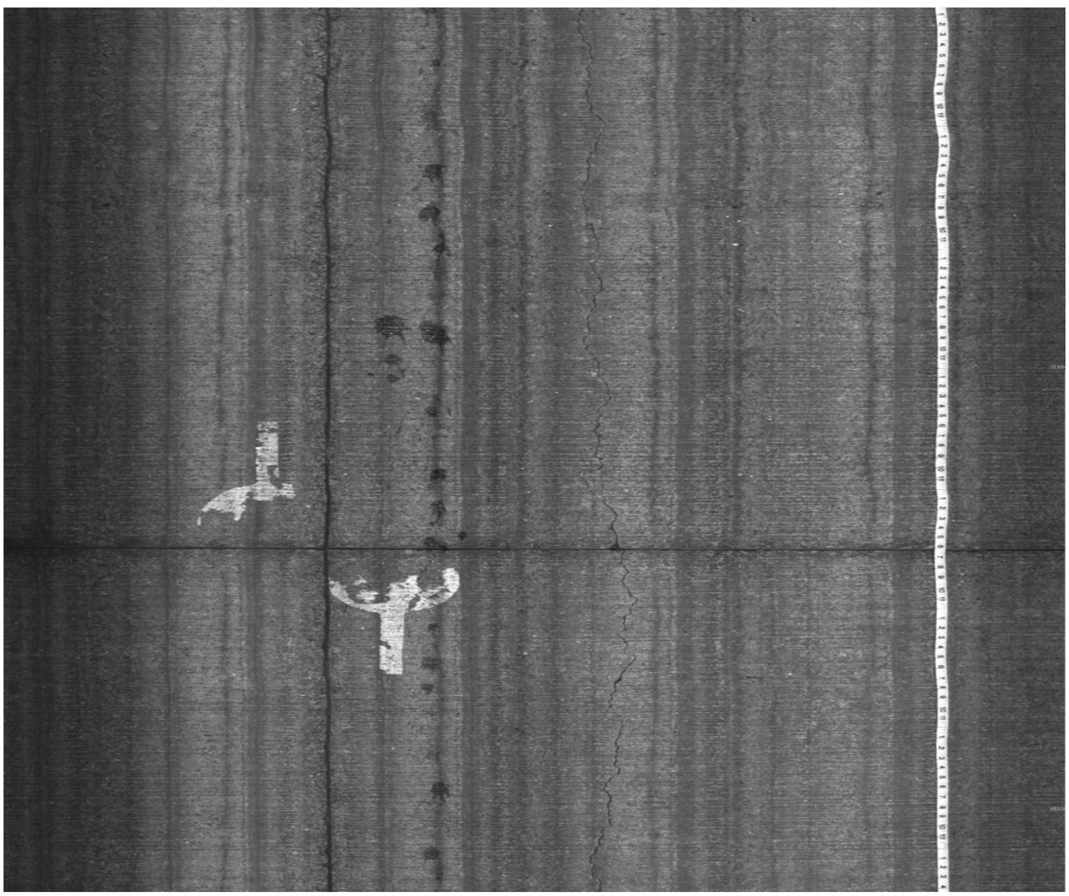

Figure 8. Digital Image of Surface Distress.

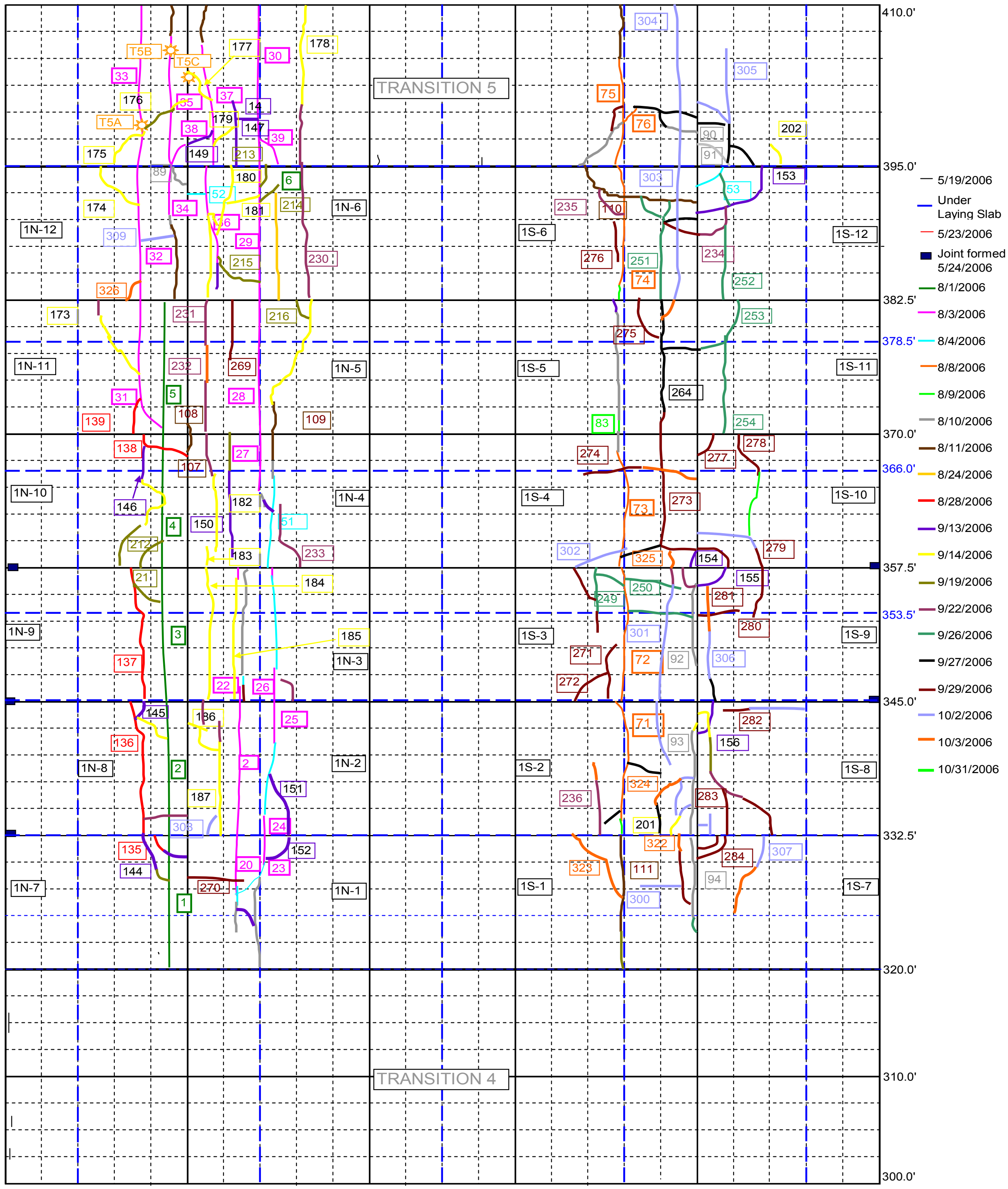

Figure 9. Distress Map for Structural Section 1.

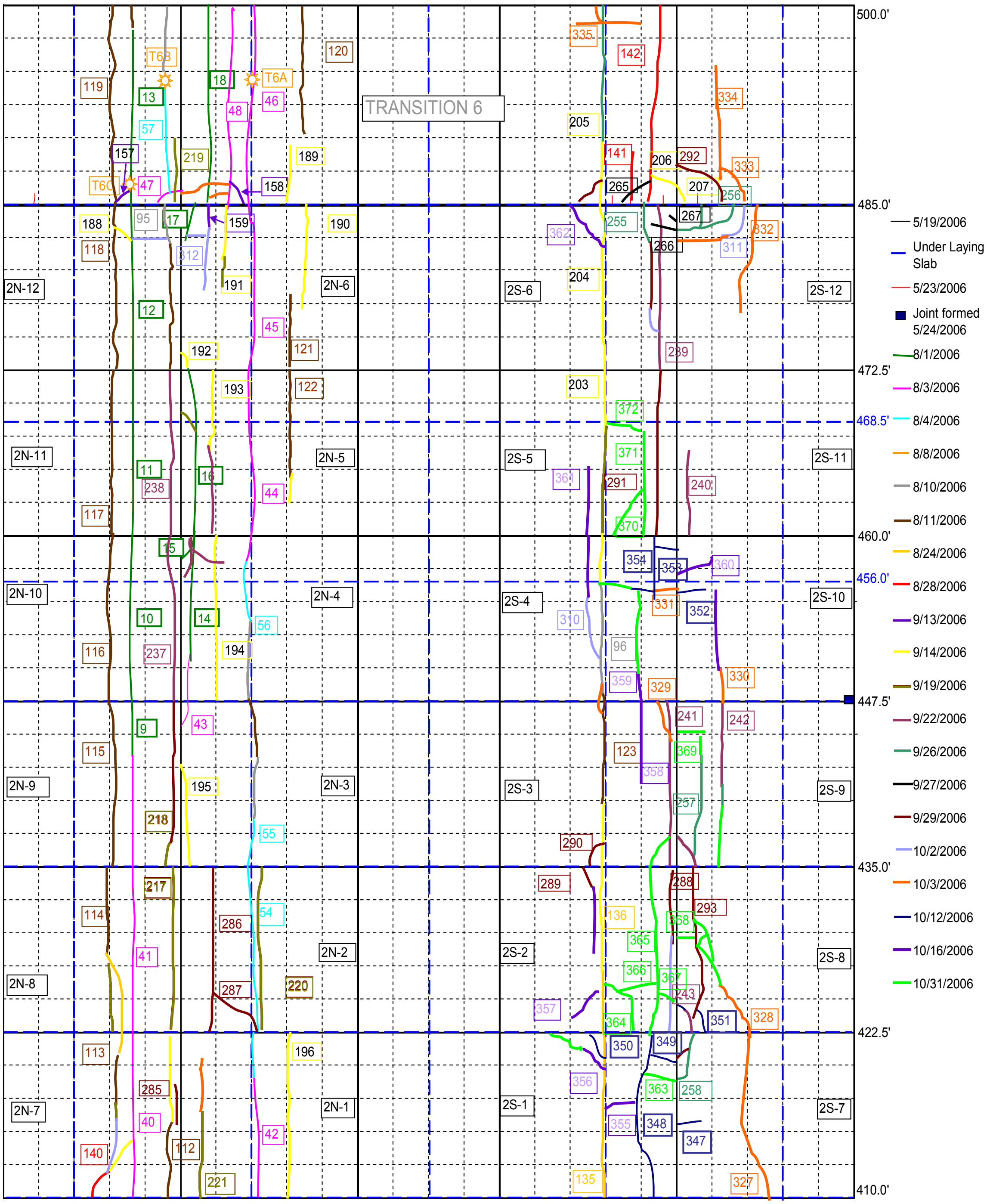

Figure 10. Distress Map for Structural Section 2.

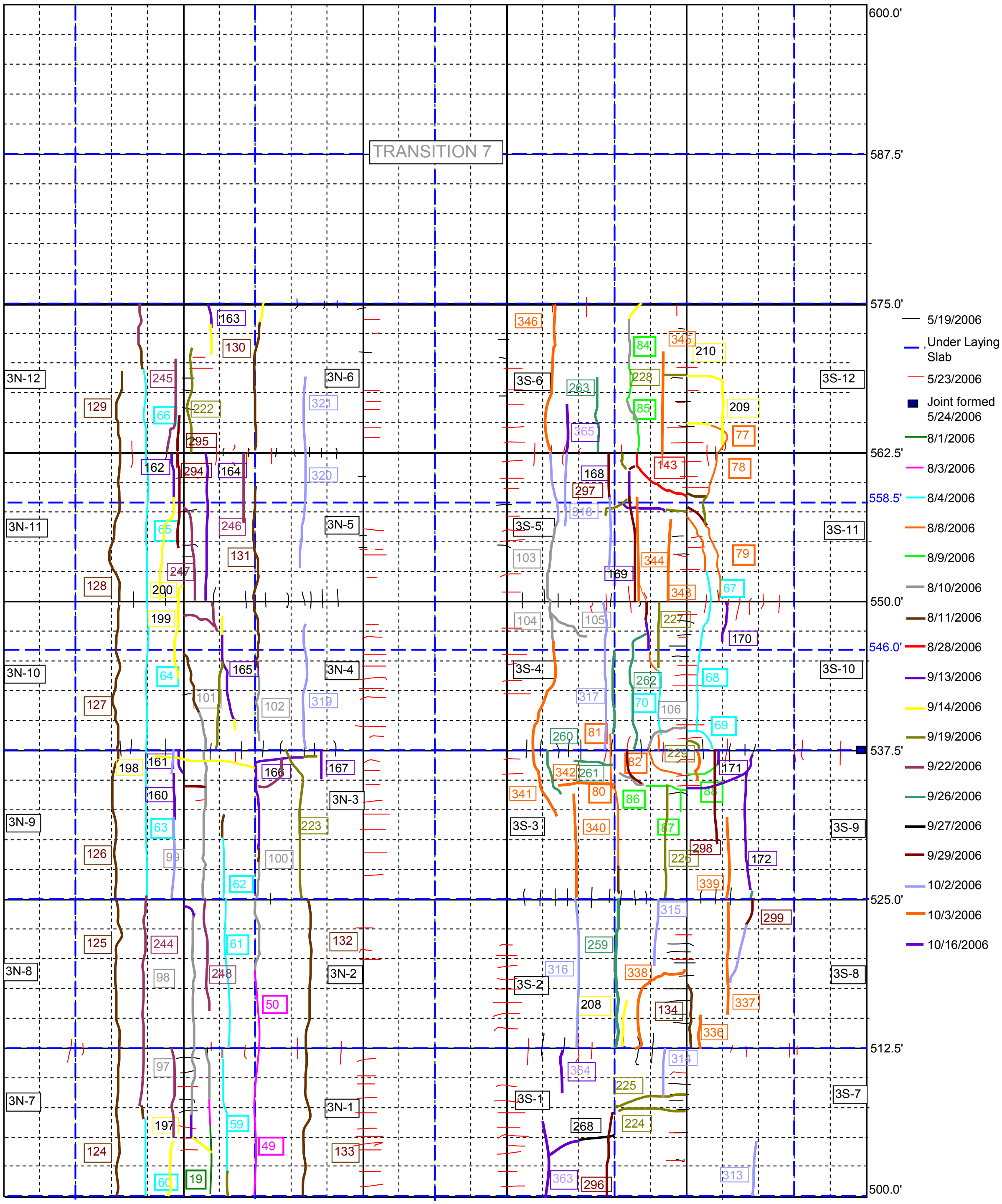

Figure 11. Distress Map for Structural Section 3.

DISTRESS OBSERVATIONS

Tridem loading on the North test items took place from July to October 2006. The primary distress which developed under the tridem load was longitudinal cracking. Longitudinal cracking first developed during early August. Sections 1 and 3 developed distress earlier than section 2. This cracking developed first along the interior longitudinal joint within the wander pattern in the top slab, and inside the outer longitudinal joint within the wander pattern in the top slab. Additional longitudinal cracking also developed between the two longitudinal joints early in August. Additional interior cracking developed during early September. By September 19, the tridem sections had reached an SCI in the 20's, and loading of these sections was discontinued.

While longitudinal cracking was also a primary mode of distress under the tandem load, other transverse and "circular" crack patterns ultimately developed, particularly around joints. Loading began at the same time for both tridem and tandem sections. However, loading of the tandem (South) test items continued until October 31, 2006. Sections 1 and 3 were loaded until Oct. 16, while loading of section 2 continued until the end of the month. Similar longitudinal cracking developed in these sections during August, but required higher loading repetitions to advance to the same extent. Additional cracking which appears to be associated with localized stress patterns also developed from August 11 to 28. Sections 1 and 3 reached the terminal SCI level by October16. Section 2 developed significant additional distress between October 16 and October 31.

From the distress patterns, and consideration of the stress patterns from EverFE analysis, it appears that the tridem loading has resulted in the development of cracking in the top slab as a result of tensile stresses. While similar longitudinal cracking developed under the tandem loading, it is evident that additional distress related to load concentration has also appeared. EverFE analysis indicated significantly different stress patterns for the tandem sections. It must be noted that the tandem loaded section experienced far more load passes before reaching the terminal SCI value.

Detailed analysis of the cracking is ongoing, including consideration of documented construction variations, stress analysis, instrumentation data, falling weight deflectometer data, cores, slab removal, and other project information. Variations in distress intensity and mechanisms within each test item are also being evaluated. The descriptions here are of the observed distresses only, and speculations as to distress mechanisms and causes would be premature.

SUMMARY

The construction and loading of the Baseline Experiment of the unbonded overlay Roadmap has been carried out successfully. In spite of minor construction defects in the asphalt interlayer, which resulted in some variation in the concrete overlay thickness, results from loading have not been obviously affected by these minor defects. Further assessment will be performed as a part of the analysis portion of the research. Ongoing work includes evaluation of the responses from the extensive instrumentation installed in both the underlay and overlay slabs, including strain gages, vertical displacements, temperatures and other data.

Table 4.
Correlation of Load Passes with Test Dates.

Date	Section 1		Section 2		Section 3	
	Total Passes		Total Passes		Total Passes	
	North	South	North	South	North	South
7/25	132	132	132	132	132	132
7/26	528	528	528	528	528	528
7/27	924	924	924	924	924	924
7/28	1188	1188	1188	1188	1188	1188
7/31	1520	1520	1520	1520	1520	1520
8/1	1652	1652	1652	1652	1652	1652
8/2	1850	1850	1850	1850	1850	1850
8/3	2062	2062	2062	2062	2062	2062
	2180	2180	2180	2180	2180	2180
		2312		2312	2180	2312
8/4	2180	2774	2180	2774	2180	2774
8/7	2180	3038	2180	3038	2180	3038
8/8						
8/9	2180	3368	2180	3368	2180	3368
	0	132	0	132	0	132
8/10	0	396	0	396	0	396
	198	594	198	594	198	594
8/11	660	1056	660	1056	660	1056
8/24	660	1056	660	1056	660	1188
	660	1188	660	1188		
8/25	660	1254	660	1254	660	1254
8/28	660	1254	660	1254	660	1254
9/13	2840	4622	2840	4622	2840	4622
9/14	3350	5132	3350	5132	3350	5132
9/19	3935	5717	3935	5717	3935	5717
9/22	5057	6839	5057	6839	5057	6839
	5057	8027	5057	8027	5057	8027
9/26	5057	9281	5057	9281	5057	9281
9/27	5057	9677	5057	9677	5057	9677
9/28	5057	10337	5057	10337	5057	10337
9/29	5057	10931	5057	10931	5057	10931
10/2	5057	11525	5057	11525	5057	11525
10/3	5057	12119	5057	12119	5057	12119
10/11			5057	12515		
10/12			5057	13109		
10/13			5057	13571		
10/16			5057	14033	5057	12119
10/17			5057	14246		
10/30			5057	15368		
10/31			5057	16424		

The loading portion of the pavement test sections resulted in the development of structural distresses. In some cases, the distress types and patterns may be other than expected, but, in a general sense, the development distresses provides information about the performance of the three pavement sections in response to the two applied loads. Thus, the experiment to this point is successful. Additional analysis will reveal greater insight into the performance of the test sections, as additional tasks in the project are completed.

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